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Characterisation of Multimode Fibres for Use in Millimetre Wave Radio-Over-Fibre Systems

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Abstract—**Millimetre wave radio-over-fibre links using both single mode and, for what is believed to be the first time, multimode fibres are demonstrated over a 0-50GHz bandwidth using a external Mach-Zehnder modulator operating at 1550nm. The multimode fibre links show the potential for use in low cost, distributed antenna systems.**

Keywords: ***Millmetre wave, Radio-over-fibre, Mach-Zehnder Modulator.***

I. INTRODUCTION

The demand for high speed communication is increasing exponentially and during the past few years the idea of high speed in-building/campus wide Radio-Over-Fibre (RoF) links at millimetre-wave (mm-wave) frequency bands have attracted much attention[1]. The mm-wave frequency bands are becoming attractive because at higher frequencies (> 40GHz) and especially at 60GHz they offer large transmission bandwidths and also overcome the problem of spectral congestion at lower frequency ranges [2]. In addition, mm-wave radio systems enable efficient frequency reuse due to the limited propagation distances at these frequencies. The 60 GHz band has a specific attenuation characteristic caused by water molecules (rain) and oxygen in the atmosphere i.e. (10-15 dB/Km at 60 GHz) [2] which means for long-distance (> 2 km) links, many small closely spaced cells with small antennas will be necessary. Coaxial cables also become very lossy at 60GHz and thus optical fibre becomes attractive and is emerging as an ideal medium for the distribution of mm-wave signals due to its low loss, low cost, large bandwidth, and immunity to electromagnetic interference characteristics.

For future high data transfer rate multimedia and VoIP based applications, mm-wave RoF-links are considered to be a very good solution and they typically use single-mode fibre (SMF). RoF systems have already been demonstrated and tested in the 60GHz frequency band using 20km of SMF [3] and 37GHz frequency bands using 50km of SMF [4, 5]. There are both commercial as well as military applications of this technology. Commercial applications include broad-band signal distribution of interactive multimedia services to the home [4, 5] and personal radio communication [6]. Examples of military application are Doppler radar [7] and phased array antennas [7]. SMFs are usually selected for long distance and high data rate RoF transmission systems but it is also desirable to utilize the existing fibre infrastructure to minimise the fibre installation and maintenance costs. However, the majority of the buildings in U.S and Europe already employ legacy links of 62.5μm Multimode Fibres (MMF) with typical link lengths of 300m–500m, this MMF normally has a bandwidth as low as 160MHz.km at a wavelength of 850nm [8]. If this MMF fibre base could be reused for the transmission of mm-wave RoF links, it could save huge fiber installation costs enabling a new generation of mm-wave communication systems to be developed.

There has been much work carried out on extending the usable bandwidth of MMF [8, 9]. It was found [9] that even though the baseband bandwidth of MMF is limited to 500MHz.km for a wavelength of 1310nm, there are flat passband regions which extend into the microwave region. This occurs when a particular subset of modes are excited by the launch condition. The interference of these modes at the receiver will produce regions of high transmission which can be used for transmission of baseband data. Thus, MMF has been used at much higher data rates and frequencies than had been thought possible. Recently results have been shown as high as 25GHz [10]. It is interesting to postulate what is the maximum frequency to which these passbands extend. This paper seeks to extend the measurement region into the mm-wave band upto 50GHz. Preliminary results show good transmission properties to 50GHz and systems for the transmission of multi-GB/s baseband data over such links using subcarrier modulation techniques [8] are now being developed.

In this paper, we demonstrate a mm-wave RoF link up to 50GHz using a 40Gb/s External Optical Intensity Mach Zehnder-Modulator (MZM) with a 1550nm tuneable laser light source over different lengths of SMFs and MMFs for future in-building/campus wide links. First, we will describe the SMFs based RoF links and the chromatic dispersion problem that limits the link length and its solutions, and then we will show results for MMF based RoF links.

II. SMF BASED ROF LINKS

SMFs are normally used as the transmission medium for long haul systems and millimetre wave RoF systems using

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SMF at the frequency ranges of 37GHz to 60GHz [3, 4, 5] have already been demonstrated. In SMF, signal-quality degradation is usually negligible for (< 1km) links. Although dispersion-induced RF-signal fading is not a problem at low radio frequencies, it does become problematic when operating in mm-wave frequency bands [11]. Gliese *et al* [11] show that in standard SMF the dispersion of 17ps/nm/km at 1550nm wavelength causes time lag between the modulation sidebands, and at 60GHz a 1dB penalty was induced after 500m of standard SMF. Beyond 1km the dispersion problem can become so severe that the original signal can be completely cancelled out. Smith *et al* [12] proposed two solutions for overcoming the chromatic dispersion in SMF based links using external modulators. The first method was to increase the link distance by varying the MZM chirp parameter and the second method uses a single sideband (SSB) modulation technique by implementing a dual-electrode MZM. Externally modulated or directly modulated Mode-locked lasers (MLLs) may also over come the dispersion problem [4]

A number of techniques for the generation, modulation and distribution of mm-wave modulated optical carriers for mm-wave RoF links are already described in [4, 13]. Some of these methods include the use of pulsed lasers or hybrid modelocking technique [4], resonantly enhanced semiconductor lasers [13], optical heterodyne and self-heterodyne techniques [13]. Reference [4] also analysed and characterised the effect of fiber chromatic dispersion in a hybrid MLL based setup and it is shown that optical carriers generated using this setup with a repetition frequency of 37GHz can be used to a transmit broadband signals over a fiber length of 50-km using subcarrier frequencies of less than 3 GHz.

The simplest technique for the transmission of data at mm-wave frequencies for RoF systems is a direct-detection scheme incorporating an external modulator. When an external intensity modulation scheme is applied, RF-modulation of the optical carrier produces many optical modulation sidebands, which are spaced at the RF frequency on both sides of the optical carrier. Sometimes due to a relatively low modulation index, the optical spectrum is reduced to only a single carrier with two modulation sidebands. When this modulated optical signal propagates over fiber, each spectral component experiences different phase shifts due to fiber chromatic dispersion. At the optical receiver, the phase shifts cause relative phase differences in the two RF beat signals, which results in a power penalty in the combined RF signal. Complete cancellation of the RF-power can occur if the phase difference between the two beat signals is equal to 180°. This effect is dependent on the modulation frequency, the fiber dispersion parameter, and the fiber transmission length [14]. The following sections show measured results for both SMF and MMF links. They show the severe degradation that can occur in SMF and also that MMF shows the potential for use in mm-wave systems.

III. Link Measurement Experiment

A. *System Setup*

The experimental link setup is shown below in Figure 1.

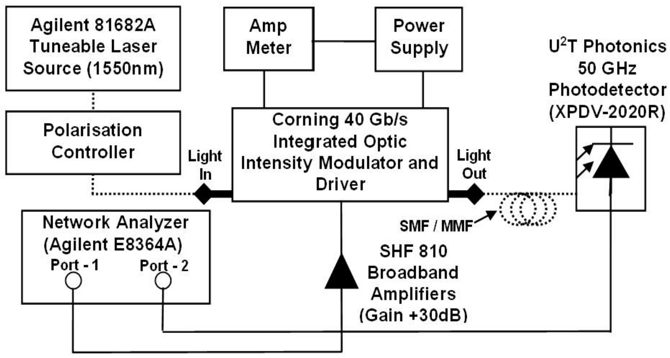

Figure 1. Setup diagram of the External Modulator based 50GHz link

In this setup, an Agilent 81682A CW-tuneable laser is used as a 1550nm light source. The 1550nm signal is fed into a polarization controller and then into a Corning 40Gb/s Integrated Optical Intensity ($LiNbO_3$ Mach-Zehnder) modulator. At the receiving end a U^2T Photonics 50GHz Photodetector (XPDV-2020R) is used to detect the optical signal. An Agilent E8364A Vector Network Analyser (VNA) is used to apply the RF modulation at the mm-wave frequency range. Port-1 of the VNA is connected to the SHF 810 broadband amplifier which is used to drive the MZM at a bias voltage which is close to $V_\pi/2$ [15] and port-2 of the VNA is connected to the U^2T photodiode.

B. *SMF Link Gain Results*

Figure 2 below shows the measured link gain results for the back-to-back system and two different lengths of SMF. The solid line shows the basic system link gain which is a function of modulator slope efficiency, input optical power and photodiode responsivity. There has been much work done to optimize this [15], but we have not employed these techniques here since we are primarily interested in the effects of the fibre as opposed to the transmitter and receiver. Thus, we can see that the back-to-back system performance rolls off up to 50GHz, but we are sufficiently above the VNA noise floor to take accurate measurements of the effect of fibres inserted into the link. The dashed line shows the effect of a 20km SMF fibre. The first point to note is the drop in the low frequency link gain, this is largely due to the 4-5dB of optical loss being introduced by the fibre and RF loss will be twice the optical loss. The second important feature is the large dip in the link gain observed around 13GHz. This is the sideband cancellation effect that was discussed earlier. Thus if one of these dips coincides with the mm-wave carrier frequency the system would no longer function. A second fibre is also measured which is slight longer at 21km and has a slightly lower cancellation frequency as expected.

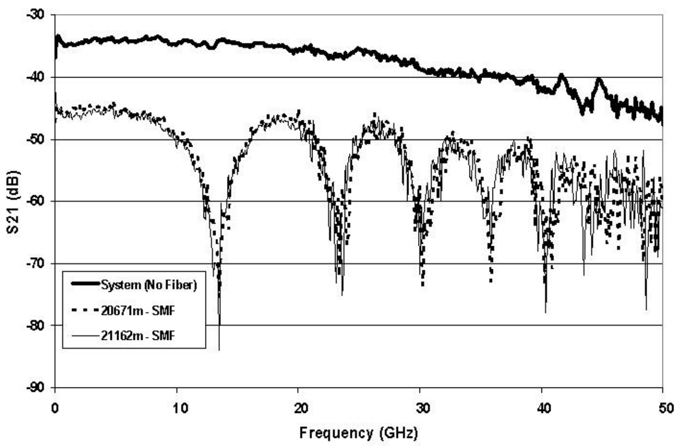

Figure 2: Link Gain results for 20km and 21km of SMF

Having characterised the simple case of SMF, the next section will observe the effects of introducing MMF into the link.

C. MMF Link Gain Results

Figure 3 shows the results for the back to back system and a 500m length of 50μm core diameter MMF.

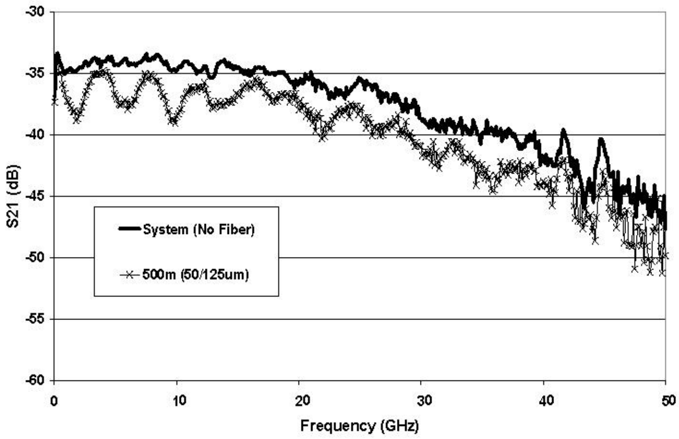

Figure 3: Link Gain results for back-to-back RoF system and 500m of MMF

The results show the strikingly different performance obtained for MMF as opposed to SMF. Obviously since the length is much shorter, the optical loss will be less and thus there is only a few dB drop at low modulation frequencies. The major difference is the lack of a large cancellation dip due to the strongly multimode nature of the propagation. One of the difficult factors when using MMF is that performance can differ widely from one fibre to another due to differences in manufacturing tolerances. To this end we have measured a range of fibre and the results are shown in figure 4.

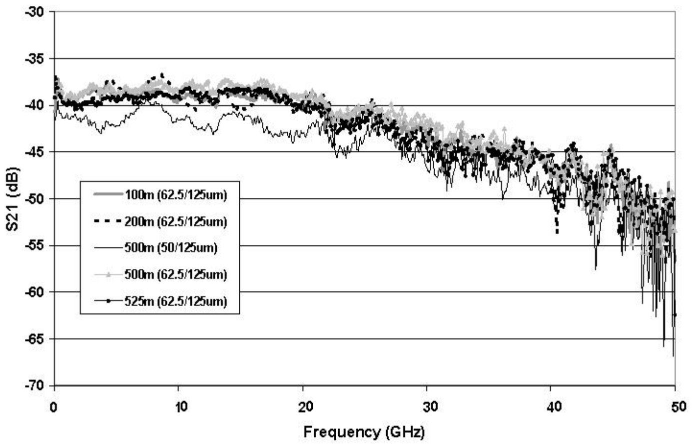

Figure 4: Link Gain results for different lenghts of MMFs

Figure 4 shows that for a number of different fibres good performance is being maintained.

IV. Conclusions

This paper has shown what are believed to be the first characterization results for standard MMF operating in a radio-over-fibre link upto 50GHz. The multimode nature of the fibre means that there are large passband regions which could potentially be used as part of a mm-wave communications system. Sub-carrier modulation techniques will now be used to up-convert standard baseband data streams for transmission over these links to assess whether they are feasible for mm-wave applications.

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